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A BIOCHEMICAL STUDY OF THE METABOLISM OF MENTAL WORK

BY

HYMAN GOLDSTEIN, PH.D.

ARCHIVES OF PSYCHOLOGY
R. S. WOODWORTH, EDITOR
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A Biochemical Study of the Metabolism of Mental Work

CHAPTER I

INTRODUCTION

A. The Problem

It is becoming increasingly apparent that a great many psychological phenomena must be interpretated from physiological viewpoints. The organism is to be regarded as an aggregate of physicochemical systems functioning in dynamic relationship to each other. The field of biological chemistry looms large as the possible final court wherein many of the perplexing problems of physiological psychology will ultimately be settled.

A major problem of physiological psychology that would appear to be amenable to biochemical investigation is the problem of the cost of mental work. If it were possible to determine the biochemical factors relating to the above problem it is evident that an approach to its solution would have been initiated.

More concretely stated, the problem of the first part of the investigation is to determine whether the metabolic changes, as measured biochemically, of a 3-hour period of cancelling A's differs significantly from the metabolic changes of a 3-hour period of more difficult mental work, *i. e.,* taking the Thorndike CAVD Intelligence Scale, levels M to Q. It would thus be possible to see, on the one hand, the relationship between the biochemical changes studied and the amount of overt muscular work and, on the other hand, the relationship between these biochemical changes and the amount of difficult ''mental'' performance.

B. The Literature

1. *Mental Work*

In spite of the fact that so-called ''mental'' work is to some degree bound up with muscular work and that both are always associated with a period of time necessary for the performance of the work, biochemical and metabolic studies pertaining to mental work, muscular work, and fasting *per se* are for purposes of convenience treated separately below.

Some investigators have reported results that would indicate that mental work produces metabolic changes.

Becker and Olsen (1) made a study of respiration and CO_2 elimination during mental work. When the subjects memorized meaningless syllables there was an increase in CO_2 elimination. While a fraction of this might arise from muscular movements, they believed that there was in addition a true increase in metabolism that was parallel to the amount of mental work performed as determined by the estimations of the subjects. However, CO_2 elimination is not a reliable index of the metabolism under changing conditions, due to its lability (2, p. 72) (15, p. 409).

Matsushima (41) reported that mental work in 10 subjects increased O_2 consumption about 5% over that of absolute rest. Rounds, Schubert and Poffenberger (53) found that mental multiplication resulted in a 28.8% increase in O_2 consumption over the resting rate in one subject.

Hefter and Judelowitsch (28) found that prolonged and intense mental work resulted in a lowered alkali reserve while the blood lactic acid remained within normal limits during the mental exertion. Levitina, Levina, Chernomordik, Samichkina, Sidorova and Shapiro (38) found a decrease in alkali reserve and an increase in inorganic phosphorus of the blood after two hours of psychotechnical tasks. The lactic acid content was unaffected. Taranowitsch (59) reported increased organic phosphorus excretion in urine after prolonged mental fatigue.

Myerson and Halloran (44) by puncture of the internal jugular vein and the carotid artery studied the brain metabolism and found decreased sugar, decreased O_2 content and increased CO_2 content of the blood after coursing through the brain. No change was observed in phosphates, calcium and chloride content of the blood. Lennox (36) took blood from an internal jugular vein in 15 cases before and during reading and the performance of problems in mental arithmetic. In two-thirds of the cases the O_2 content of the blood leaving the brain was increased (average increase was 0.9% by volume) while CO_2 content was decreased. Lennox believed that the observed increases were presumably due to a dilatation of the cerebral vessels.

Another group of investigators, however, have reported results that would cast considerable doubt on the existence of marked metabolic changes as a result of mental work.

Speck (58) found that his metabolism increased 8–10% during mental work, but this effect was ascribed to small muscular movements impossible to eliminate and which were due in general to bodily discomfort. Loewy (39) found that the metabolism of natural sleep did not differ from the metabolism while awake.

Benedict and Carpenter (3) studied the effect of mental activity on the metabolism of 22 students during examinations while the students were exerting intense mental effort. They found the metabolism only very slightly greater during this period than during a period of comparative mental rest, *i. e.,* little mental effort was apparently involved. They attempted to keep the amount of physical work constant in both the mental work period and the control period. Benedict and Benedict (2) studied the effects of mental multiplication on the CO_2 elimination and O_2 consumption of 7 subjects and found that the extra caloric demands of mental effort were very small, the increase in O_2 consumption being about 4%, which was largely accounted for by the increased muscular activity accompanying the increased ventilation of the lungs and the increased heart rate. The response to mental effort was observed to be immediate and not cumulative. The authors concluded that mental effort *per se* is without significant influence upon the energy metabolism.

Johnson (31) studied the changes in blood sugar content of 8 children after tests involving fairly complex mental reaction, *i. e.,* test of coördination, discrimination, memory for digits and substitution. Some children showed increases, others decreases. Affective factors were not taken into consideration. Knipping (34) found that mental work is accompanied by only small increases in heat production and increased phosphates in the blood. Kestner and Knipping (33) showed that the O_2 consumption and the CO_2 elimination were increased very little by mental work and confirmed Knipping's (34) results.

2. *Muscular Work*

Most investigators have reported increased creatinine and phosphorus values in blood and urine after muscular work. It is known that during muscle contraction phospho-creatine is hydrolyzed with the production of inorganic phosphate and creatine (20). The sugar in the blood which represents a supply of immediately available energy is decreased with muscular work (51).

Wahl (63) and Schulz (55) reported that muscular work increased the creatinine output. Campbell and Webster (7) showed that a prolonged period of muscular work increased creatinine significantly. Kacl (32) found that immediately after muscle exercise the total creatinine of the blood may increase about 0.47 mg. per 100 cc. of blood and the creatine may increase 0.48 mg. From these values he concluded that immediately after work the total creatinine of the blood is increased 44.7% and the creatine 72.9%. After a rest of 3 hours the creatinine and creatine values returned to their original level or even fell below that. The increase in blood creatinine bore no relation to the degree of exertion. Planet and Cardoso (50) found that during exercise blood phosphorus and creatine increased 30–90%. Carpentier and Brigaudet (10) reported increased urinary creatinine after muscular work. Palmieri (47) reported the same findings and indicated that the increase is not directly proportional to the amount or duration of work but depends on the individual physiological reaction to fatigue. Shaffer (56) found that creatinine in urine is an index of muscular metabolism.

Wilson, Long, Thompson and Thurlow (66) found that strenuous exercise resulted in increased urinary phosphorus excretion. Haldane, Wigglesworth and Woodrow (26) found the same results for blood phosphorus. Jervell (30) detected small increases in blood inorganic phosphorus after muscular exercise. Efimov and Samichkina (16), Dill, Talbot and Edwards (14) and Owles (46) all reported increased blood phosphorus after exercise. Gemmill and Ribeiro (25) found that when exercise is prolonged an increase in inorganic phosphorus was obtained. They found that the breakdown and reconversion of phospho-creatine during violent exercise of short duration was completely reversible.

Rakestraw (51) found that prolonged exercise for two or three hours was followed by a drop in blood sugar in 21 male subjects. Madon and Goldberger (40) reported that blood sugar is always less after labor than during rest. Christensen (12) could find no relation between blood sugar, intensity of work and degree of fatigue.

Several investigators have failed to find the biochemical changes just mentioned. Rakestraw (51) could not find appreciable changes in blood creatinine and cholesterol after prolonged exercise for two or three hours. Irving and Bastedo (29) found no significant increase in inorganic phosphorus during prolonged muscular work. Patterson (48) reported that blood cholesterol was not affected by exercise. Bock, Dill, Hurxthal, Lawrence, Coolidge, Dailey and Henderson (6) found no effects of exercise on serum chloride. Madon and Goldberger (40) reported that fatigue caused no change in the calcium content in 4 individuals.

3. *Fasting*

There are not many studies either on diurnal variation of the constituents of the body fluids or on the effects of fasting on these constituents.

Some of the studies have shown that in general phosphorus tends to increase as a result of diurnal variation during the morning, reaching its maximum at about the middle of the afternoon.

Mulder, Phillips and Visscher (42) found that fasting human subjects excreted more urinary phosphate than could have been derived from the protein metabolized. Fiske (19) found an increase in phosphate output during the morning, reaching its maximum at about the middle of the afternoon. Campbell and Webster (8) have shown that sleep produced a significant rise in inorganic phosphorus, and sleep at whatever period of day or night always leads to high phosphate excretion in the urine. Haldane, Wigglesworth and Woodrow (26) have confirmed this. In general, blood phosphate changes run parallel to urinary phosphate changes (49, p. 1109).

Lennox, O'Connor and Bellinger (37) and Shope (57) reported that only in prolonged starvation is there a decrease in blood sugar. Shope (57) found increased cholesterol during prolonged fasting in one subject who was not quiescent but led an active life during the period. Gamble, Ross and Tisdall (23) reported a decrease in plasma chloride concentration in 4 children during a fasting period. Kacl (32) reported that resting decreased the creatine and creatinine contents of human blood.

A few investigators have failed to corroborate several of the above findings. Among these may be mentioned Chauveau (11) who, in an experiment on horses and dogs, found that blood sugar did not decrease during a moderate period of fasting. Lennox, O'Connor and Bellinger (37) found no significant effect of fasting on cholesterol in 24 subjects.

PART I

Mental Work with Overt Physical Component

CHAPTER II

METHODS AND PROCEDURE

A. Methods

It was deemed advisable to secure blood samples instead of urine specimens for biochemical analysis because the products of metabolic changes must of necessity traverse the blood stream before being excreted. Rowe (54, p. 146) has stated the fact admirably:

> The blood is the great thoroughfare of the body both for the ingress of absorbed materials and the egress of body wastes. The delicately balanced regulating mechanisms of the body maintain the concentrations of certain important constituents at surprisingly constant levels when they are determined under definite conventional limitations. To this fact is attributable the very real significance that attaches to such levels.

It was felt thus that a more accurate picture of metabolism could be secured from blood analysis than from urine analysis. Furthermore, blood specimens could be secured at the will of the experimenter before and after experimental sessions. Such was not the case with the procuring of urine samples. Thus the matter of practical expediency entered into the selection of the body fluid for analysis.

In the preliminary experimentation there were included the determinations of the hemoglobin, inorganic phosphorus, acid-soluble phosphorus, lipoid phosphorus, total phosphorus, cholesterol, sugar, calcium, chlorides, and creatinine contents and the CO_2 combining capacity of the blood. Because of the unsuitability[1] for various reasons of five of these determinations and because such a large number of determinations would make the analytical work cumbersome and unwieldy, it was decided to continue with the six determinations mentioned below.

---

[1] The Newcomer acid hematin method (45) for hemoglobin was found to possess too large an error. The Youngburg method (67) for lipoid phosphorus, acid-soluble and total phosphorus was found to be unreliable, occasionally failing entirely to work. The Whitehorn (64) and Bloor (4) methods were employed to determine these constituents but without consistent success. The Van Slyke and Cullen method (62) for CO_2 combining capacity determination gave values that were too low. Since the CO_2 combining capacity determination was of necessity the last one in a routine series of determinations made because of the necessity of securing plasma from whole blood, there was an unavoidable interval of 2 to 3 days between the time of securing the blood and the time of analysis. This delay probably resulted in an apparently decreased alkali reserve.

1. *Inorganic Phosphorus*

The normal inorganic phosphorus content of the blood plasma is from 3 to 5 mg. per 100 cc. Phosphate is known to be concerned in carbohydrate metabolism (27, p. 456) (49, p. 1117). A compound of phosphoric acid and creatine, phospho-creatine, has recently been isolated from muscle. During muscle contraction phospho-creatine is hydrolyzed with the production of inorganic phosphate and creatine. During recovery, part of the inorganic phosphate and creatine recombine. This does not mean that all of the inorganic phosphate found in the blood originates from phospho-creatine nor that all of the inorganic phosphate recombines with creatine during recovery to form phospho-creatine. The breakdown of adenylparaphosphoric acid and the breakdown of the hexose phosphates also produce inorganic phosphate. However, much of the inorganic phosphate is now known to originate from phospho-creatine (49, pp. 1092, 1094). In view of the fact that several studies (38) (59) referred to above have reported increased phosphates after mental work and in view of the fact that several studies (14) (16) (26) (30) (46) (66) also referred to above have reported increased phosphates after muscular work, it was deemed essential to include the inorganic phosphorus determination. The Youngburg method (67) for inorganic phosphorus with about 10% error in recovery was used. (Error in recovery always refers to amount of error mentioned by those who devised the methods.)

2. *Cholesterol*

Normal whole blood contains 140–200 mg. cholesterol per 100 cc. blood. Cholesterol is an unsaturated secondary alcohol with the formula $C_{27}H_{45}OH$. Furthermore, it possesses the characteristics of a complicated terpene (27, p. 228). Its widespread occurrence in the tissues, particularly in nerve tissues, suggests that it must play some important part in the regulation of the mechanisms of the cell. However, its exact constitution and much concerning its rôle in normal and abnormal metabolism remain to be solved. Myelin, the fat-like, semi-fluid substance that forms the medullary sheath of medullated nerve fibers, is a complex substance containing phosphatides, cerebrosides and cholesterol. Cholesterol is abundant in the white matter of the brain and increases in this substance early in life (49, pp. 227, 228). In view of the abundance of cholesterol in the white matter of the brain, it was believed that there might possibly be some connection between the changes in cholesterol concentration and neural activity. The Bloor method (5) for cholesterol with about 5% error in recovery was used.

3. *Sugar*

Normal blood contains from 90 to 120 mg. sugar per 100 cc. blood as determined by the method used in this study. When glucose is burned intermediate products are first formed, which are then further oxidized in several steps to the final products, carbon dioxide and water (49, p. 84). Since the blood sugar is a good index of the energy that the organism has immediately available to meet its energy requirements and since it has been shown that prolonged muscular work results in decreased blood sugar (51) and also that sugar metabolism plays a part in emotional disturbances (9, p. 66), it was decided to include the blood sugar determination. The Folin and Wu method (22) for sugar with a 1% error in recovery was used.

4. *Chlorides*

Normal serum contains 560–630 mg. chlorides (calculated as sodium chloride) per 100 cc. blood. Chlorides are found in all the tissues of the organism. The chloride ion is the major anion of the blood and it seemed to be of interest to determine whether the chloride concentration of the blood was affected by the experimental conditions of this investigation. The Wilson and Ball modification (65) of the Van Slyke method (61) with a 1% error in recovery was used.

5. *Calcium*

Normal blood serum contains 9–11.5 mg. calcium per 100 cc. Calcium has an influence upon the excitability of the motor systems of animals (49, p. 805). In tetany there is a deficiency in the calcium concentration of the blood. Since motor functions were to be called into play in the particular types of work that were to be used in the experiment, it was thought necessary to include the calcium determination. The Clark-Collip modification (13) of the Kramer and Tisdall method (35) with a 1% error in recovery was used.

6. *Creatinine*

Normally creatinine is found in blood to the extent of 1–2 mg. per 100 cc. Creatinine is the internal anhydride of creatine. It is derived from creatine by the abstraction of a molecule of water. It appears probable that creatinine is a waste product formed from creatine which is a constituent of muscle and hence it is a product of muscular metabolism (49, p. 456). As mentioned above, during muscle contraction phospho-creatine is hydrolyzed with the production of inorganic phosphate and creatine (20). Since it was possible that the blood creatinine values might give some information regarding the extent of the muscular metabolism involved in the types of work used in this experiment, it was deemed necessary to include the creatinine determination. The Folin and Wu method (21) with a 10–15% error in recovery was used.

Duplicate determinations were not performed in the experimental analyses. However, preliminary experimentation showed that quadruplicate samples of the same specimen checked highly. Table 1 gives the determination of quadruplicate samples of the same blood specimen with the averages of these determinations and the percentage errors for inorganic phosphorus, cholesterol, sugar, chlorides, calcium and creatinine in mg. per 100 cc. of blood.

TABLE 1

Determinations of Quadruplicate Samples of the Same Blood Specimen in mg. per 100 cc. Blood, in Inorganic Phosphorus, Cholesterol, Sugar, Chlorides, Calcium and Creatinine

Sample	*Inorganic Phosphorus*	*Cholesterol*	*Sugar*	*Chlorides*	*Calcium*	*Creatinine*
1	5.36	229	160	585	11.78	1.62
2	5.21	232	162	594	11.78	1.75
3	5.43	236	160	587	12.52	1.61
4	5.43	232	162	593	11.53	1.70
Ave.	5.357	232.2	161.0	589.7	11.903	1.670
Percentage Error	4.1%	3.0%	1.2%	1.5%	8.3%*	8.4%†

* It is possible that insufficient washing out of the ammonium oxalate accounted for the rather high value of 12.52 mg. of calcium in sample 3. This high value in large part accounts for the 8.3% error of these quadruplicate calcium determinations. Fales (17, p. 71) states that when in a series of four observations one differs widely from the other three it is permissible to omit the doubtful observation if the difference between the doubtful observation and the arithmetic mean of the other three observations is four times or more the average deviation of the other three determinations. The 12.52 mg. calcium observation fulfills these requirements for omission. When this observation is omitted, the calcium percentage error is 2.1%.

† The 8.4% error for creatinine is not unusual. The difficulty of matching yellow colors probably accounts largely for the error. Myers (43, p. 572) states that "with normal bloods the color development is weak, and yellow colors at best are hard to match." Folin, in a personal communication to the author, states that the percentage error for creatinine has practically no significance, since one is dealing with only about one mg. per 100 cc. blood.

B. Psychological Tests

1. *Intelligence*

The Thorndike CAVD Intelligence Scale, Levels M–Q (60) measures increase in intelligence in levels or units of equal value at any part of the scale. Besides furnishing a more extensively graduated range of difficulty than any other intelligence scale, the test also permits, for the first time, measurements from an empirically determined ''absolute zero'' of intellect. Thus it is superior to the usual intelligence examination since individuals may be compared with respect to absolute ability in the functions measured by the scale (24). The levels M–Q are particularly adapted to college students and only about 20% of college graduates pass level Q (get more than 50% correct). The reliability is about +.80 and the validity is about +.70 (60, p. 99).

2. *Rating Scale*

The author devised a rating scale upon which the subjects were to record their degree of feelings of physical fatigue and of mental fatigue at the end of each experimental session. It was possible to rate oneself from one to five, high values indicating much fatigue and low values indicating less fatigue. Below are given the rating instructions given to the students, which were designed to aid in avoiding possible confusion and difficulty in differentiating between mental and physical fatigue:

> Physical Fatigue: If you are fatigued physically to the state of exhaustion and feel that you are so tired that you cannot budge from your seat, rate yourself ''five'' on this trait. If, however, you are not in the least tired physically and feel ''fresh as a daisy'' rate yourself ''one'' on this trait. If your state of fatigue is somewhere between these two extremes, rate yourself accordingly, either ''two,'' ''three,'' or ''four,'' as the case may be.
>
> Mental Fatigue: If your mind is so fatigued that you believe that you cannot ''think straight'' then rate yourself ''five'' on this trait. If, however, you still feel able to tackle problems that require intense concentration and solve them with justice to yourself, then rate yourself ''one'' on this trait. If between these extremes, do as above.

None of the subjects reported any difficulty in distinguishing between these two forms of fatigue.

C. Subjects

The subjects were 19 adult males of college rank, ranging in age from 18 years 6 months to 32 years 11 months, averaging 23 years 9 months. A twentieth subject served for two-thirds of the experiment but upon the advice of a physician did not participate further. The subjects served without pay and their coöperation was excellent.

D. Procedure

In order to avoid ambiguity, the writer wishes to clarify his use of one or two of the more important terms used in this study.

By physical component or "physicalness," the author means overt or observable muscular activity. By mental component or "mentalness," the author means what psychologists refer to as thought, that is, "mental manipulation," or sub-vocal speech, or some problem-solving activity without overt or observable muscular response.

There were two aspects that presented themselves relative to the problem of the cost of mental work. In order to determine what the effect of the introduction of more "mentalness" in a task would have upon the total metabolism of the organism, it was decided to compare the metabolic changes occurring during 3 hours of cancelling A's with those occurring during 3 hours of taking a difficult intelligence test. In order to determine whether physiological cost is a function of output or of time engaged in work, it was decided to compare the metabolic changes occurring during the work where output was limited with those occurring where time was limited. For this purpose a session was introduced where the subjects cancelled 80 pages of A's. On the average, the subjects took about 2 hours to do this limited output of work.

Each subject attended 3 sessions (usually held Sunday mornings) approximately 3 weeks apart. The first and third Sundays were 3-hour periods.

Since cancellation ability is markedly influenced by practice effects, each subject was given practice sufficient to bring him up to his maximum ability (as shown by a practice curve) prior to the experimental session. For one week previous to the first Sunday the subject was given practice daily for one-half hour in cancelling A's using 20 different forms of cancellation sheets. On the day before the first experimental session he was given an hour's practice. The subject reported at the laboratory without breakfast at 9 a.m. Sunday morning and waited at least 20 minutes in a chair. His weight was recorded and an 18 cc. blood sample was taken by a physician. He then cancelled A's for 3 hours. Signals were given every 5 minutes at which he recorded his position on the sheet. At the end of 3 hours, immediately after work, an 18 cc. blood sample was again taken and he rated himself on a 5-point rating scale on physical fatigue and mental fatigue (low ratings indicating less fatigue and high ratings indicating much fatigue). He also recorded relevant introspections (Period I).

Approximately three weeks later he was given one hour's practice in cancelling A's on the day before the second experimental session. He reported at the laboratory without breakfast on Sunday morning at 9 a.m. The same procedure was followed as in the first session but this time he was given 80 pages of A's to cancel (requiring about 2 hours on the average to complete). Whereas previously the cancellation scores were recorded, this time the cancellation times were observed. Blood was taken before and immediately after the session.[2] Again he rated himself and recorded introspections (Period II).

Approximately three weeks later he reported at the laboratory without breakfast on a Sunday morning at 9 a.m. and waited 20 minutes in a chair. Weight was recorded and blood was taken. He was then given the CAVD Intelligence Scale, Levels M–Q, for a 3-hour period. In the event that he finished before 3 hours he was given the Roback Mentality Test for Superior Adults (52). At the end of three hours, immediately after work, blood was taken and ratings and introspections were recorded (Period III).

In order to determine the effects of the mere passage of time itself and in order to determine the effects of markedly overt muscular work where the mental component was rather low (since the mental work used in this experiment involved an appreciable amount of muscular work), it was necessary to have control groups.

Nine subjects out of the group of 19 served as a control group in a period of tapping and in a period of "no work." In order to increase the reliability of the results, it was deemed necessary to increase the size of the control group. However, since the remainder of the original group of 19 subjects was unavailable, the control group of 9 subjects was increased to 14 subjects by 5 additional male subjects who were in general of the same age range, educational, social and economic status as that of the original group of 19 subjects. At one experimental session the control group performed tapping, that is, they tapped with a stylus on a tapping board in time to a metronome set at 126 beats per minute. Every fifth minute at a given signal the subject tapped as fast as he could for one-half minute and at the end of the half-minute another signal was given and he resumed the 126 pace. This was continued for three hours. Tapping was taken as a sample of physical work, that is, work with marked overt muscular component. From now on these two terms, tapping and physical work, will be used interchangeably.

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[2] On one occasion the physician was unavoidably delayed for 10 to 15 minutes in securing the post-work bloods of 5 subjects at the conclusion of their second experimental session. Upon analysis, however, the determinations of these samples did not differ significantly from those of the other subjects.

Even though the amount of ''physicalness'' and ''mentalness'' cannot be, of course, objectively measured, it is clear that when we contrast cancellation and the CAVD test, a proportionately greater amount of time is spent in overt muscular work in the former case, and a proportionately greater amount of time is spent in ''mental manipulation'' in the latter case.

At another experimental session the control group performed ''no work'' but relaxed in Morris chairs and on sofas in congenial surroundings. The subjects of this group were urged to sleep if possible, or if that were impossible, to read light literature, magazines or newspapers requiring no concentration. This was continued for three hours (''No Work''). On both occasions, blood samples were taken before and immediately after the experimental session and the subjects recorded ratings and introspections.

The experiment proper started the first week in November 1932 and ended the first week in August 1933, extending over a period of 9 months. Each subject attended three Sunday sessions three weeks apart. The first and third Sunday sessions were 3-hour periods. The control sessions were also 3-hour periods. The number of subjects per session varied from two to nine.

The pre-work bloods were always taken from the left arm while the post-work bloods were always taken from the right arm. It was desired thereby to avoid over-irritation of a localized area. The blood for the determinations of inorganic phosphorus, cholesterol, sugar and creatinine was drawn into oxalated bottles; that for calcium and chlorides into non-oxalated test-tubes. The blood in the non-oxalated test-tubes was centrifuged and the resulting serum was used for the calcium and chloride determinations.

In total, 170 blood specimens of 18 cc. each, equal to 3060 cc. of blood, were taken and 908 blood determinations were performed by the author with use of laboratory facilities furnished by the Department of Biochemistry of the College of Physicians and Surgeons.[3]

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[3] The author majored in Chemistry at Columbia College. In addition, he had training in biochemical techniques in the Pathological Laboratory of St. Luke's Hospital under the direction of Mr. F. Leineweber, biochemist of the Pathological Department, who checked the author's techniques and accuracy. The author has also been biochemical technician to Dr. Ross A. McFarland, performing all the biochemical determinations incidental to the research on various psycho-physiological aspects of the effects of oxygen excess and deprivation which is being conducted at the College of Physicians and Surgeons.

CHAPTER III

RESULTS

A. Work

1. *Mental Work with Overt Physical Component*

The first type of work studied was cancellation. This is a combination of simple mental work and physical work requiring attention, concentration and manual activity. The manual activity in cancellation is continuous. The second type of work studied was that involved in taking the CAVD Intelligence Test, Levels M–Q. This is a combination of difficult mental work and physical work, requiring attention, much concentration and some manual activity. The manual activity involved in taking the CAVD Intelligence Test was an occasional bit of writing after periods of concentration. The physical work involved here was believed to be less than in cancellation, while the mental work involved was believed to be more than in cancellation.

Work consisting of 3 hours of cancellation (limited time) produces certain biochemical changes. In general, there is an increase in inorganic phosphorus, an increase in cholesterol, a decrease in sugar and an increase in creatinine. Work consisting of a 3 hours' intelligence test of a difficult nature produces the same changes. There is no reliable difference between the changes occurring in cancellation and those in taking an intelligence test.

The biochemical changes occurring during 80 pages of cancelling A's (limited output) which required on the average about 2 hours to complete, do not differ significantly from those occurring during a 3-hour period of cancelling A's (limited time), except that there is a significantly greater increase in inorganic phosphorus with limited time than with limited output. The biochemical changes occurring during this period of limited output (80 pages) do not differ significantly from those occurring during 3 hours of difficult mental work.

Tables 2 to 7 give the pre-work and post-work determinations and direction of change of inorganic phosphorus, cholesterol, sugar, chlorides, calcium and creatinine in mg. per 100 cc. blood during Period I (3 hours of cancelling A's), Period II (80 pages of cancelling A's) and Period III (3 hours of difficult mental work, that is, the CAVD Intelligence Test, Levels M–Q). The averages, standard deviations, and coefficients of variation are given also for the pre-work and post-work determinations. The reliabilities of the changes were computed according to Fisher's method (18, p. 104) used in dealing with small groups. Changes or differences have been considered reliable when the chances for reliability were 95 or more in 100.

It is evident that only the inorganic phosphorus changes in Periods I and III, the cholesterol changes in Periods I, II and III, the sugar changes in Periods I and III and the creatinine changes in Periods I, II and III are reliable changes. This means that with mental work, as employed here (which necessarily involves appreciable muscular work), it is probable that hydrolysis of phosphocreatine produces inorganic phosphate and creatine. This has been found to occur in muscle contraction (20). The decreases in sugar indicate that the immediately available energy is consumed by doing the type of work used in this experiment. The interpretation of the increases in cholesterol after cancellation and after the difficult mental work is open to speculation. Below, it has been shown that tapping performed by a control group produced increased cholesterol.

The determinations of calcium and chlorides were included in the analytical procedure in the hope that work which was long continued and intense might reveal significant changes in these two blood constituents. The experimental findings of this investigation have revealed no significant changes in these blood constituents.

The differences between the changes in Periods I, II and III for each constituent were computed but they were not reliable differences, except the difference between the changes in inorganic phosphorus in Periods I and II. Fisher's method (18, p. 107) for use with small groups was employed.

2. *Physical Work with Little Mental Component*

As stated above, it was deemed essential to determine the effects on the blood constituents of work with marked overt muscular component where the mental component was rather low. It was also considered necessary to determine the effects on the blood constituents of a passage of time equal to the time taken for the performance of the work. For this purpose, there was a control group of 14 subjects that performed physical work at one session (described above under Procedure) for 3 hours and "no work" at another session (see Procedure) for 3 hours.

TABLE 2

PRE-WORK AND POST-WORK DETERMINATIONS AND DIRECTIONS OF CHANGE OF INORGANIC PHOSPHORUS IN MG. PER 100 CC. BLOOD DURING PERIOD I (3 HRS. OF CANCELLING A'S), PERIOD II (80 PAGES OF CANCELLING A'S), AND PERIOD III (3 HRS. OF DIFFICULT MENTAL WORK) IN 19 SUBJECTS

Subject	*I*			*II*			*III*		
	Pre	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*
1	3.85	4.05	+ .20	4.05	4.19	+ .14	5.28	5.36	+ .08
2	4.29	4.41	+ .12	4.05	4.21	+ .16	5.32	6.31	+ .99
3	3.75	3.85	+ .10	3.57	4.24	+ .67	5.36	5.56	+ .20
4	3.17	3.59	+ .42	6.41	5.07	−1.34	4.84	5.00	+ .16
5	4.71	3.67	−1.04	4.52	5.40	+ .88	4.21	5.28	+1.07
6	3.85	4.24	+ .39	4.17	4.19	+ .02	4.46	5.40	+ .94
7	4.05	5.56	+1.51	5.73	5.77	+ .04	4.21	4.36	+ .15
8	4.01	4.78	+ .77	5.36	6.25	+ .89	4.39	4.03	− .36
9	3.59	4.03	+ .44	6.00	5.28	− .72	4.44	5.95	+1.51
10	5.00	5.77	+ .77	5.21	4.57	− .64	3.38	3.73	+ .35
11	5.40	4.69	− .71	4.84	4.46	− .38	4.29	4.12	− .17
12	5.00	6.10	+1.10	4.19	4.46	+ .27	4.29	4.24	− .05
13	5.17	6.41	+1.24	5.32	4.63	− .69	4.63	4.24	− .39
14	3.89	5.00	+1.11	4.69	4.17	− .52	3.75	4.78	+1.03
15	4.75	4.55	− .20	4.46	3.69	− .77	4.26	5.28	+1.02
16	7.08	7.43	+ .35	6.00	6.15	+ .15	4.46	4.05	− .41
17	6.25	6.52	+ .27	4.90	4.49	− .41	3.77	3.81	+ .04
18	4.93	5.17	+ .24	4.75	5.28	+ .53	2.94	3.68	+ .74
19	5.43	5.81	+ .38	4.41	4.63	+ .22	4.93	4.46	− .47
Ave.	4.641	5.033	+ .392	4.875	4.796	− .079	4.380	4.718	+ .338
S.D.	.947	1.056	.614	.754	.699	.595	.611	.766	.592
C.V.	20.4	20.9		15.5	14.6		13.9	16.2	
Reliability of Change—		98–99 chances in 100			No reliable difference			95–98 chances in 100	

TABLE 3

PRE-WORK AND POST-WORK DETERMINATIONS AND DIRECTIONS OF CHANGE OF CHOLESTEROL IN MG. PER 100 CC. BLOOD DURING PERIODS I, II AND III

Subject	*I*			*II*			*III*		
	Pre	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*
1	165	210	+45	154	197	+43	140	178	+38
2	188	206	+18	170	197	+27	165	171	+ 6
3	181	190	+ 9	141	197	+56	141	149	+ 8
4	165	190	+25	172	174	+ 2	165	179	+14
5	206	186	−20	192	206	+14	163	174	+11
6	196	250	+54	225	227	+ 2	168	194	+26
7	152	185	+33	124	130	+ 6	129	138	+ 9
8	171	208	+37	136	176	+40	157	194	+37
9	227	263	+36	229	243	+14	206	214	+ 8
10	205	229	+24	193	198	+ 5	179	201	+22
11	150	157	+ 7	188	207	+19	127	165	+38
12	190	170	−20	144	190	+46	122	153	+31
13	136	196	+60	146	142	− 4	138	140	+ 2
14	175	182	+ 7	171	190	+19	165	150	−15
15	171	146	−24	156	201	+45	132	179	+47
16	175	173	− 2	132	164	+32	157	156	− 1
17	177	166	−11	166	164	− 2	170	174	+ 4
18	182	188	+ 6	171	174	+ 3	176	168	− 8
19	153	166	+13	165	152	−13	147	156	+ 9
Ave.	177.1	192.7	+15.6	167.1	185.7	+18.6	155.1	170.2	+15.1
S.D.	22.4	29.5	24.1	28.7	27.5	19.6	21.6	19.9	16.5
C.V.	12.6	15.3		17.2	14.8		13.9	11.7	
Reliability of Change—	98–99 chances in 100			More than 99 chances in 100			More than 99 chances in 100		

TABLE 4

Pre-Work and Post-Work Determinations and Direction of Change of Sugar in mg. per 100 cc. Blood During Periods I, II and III

Subject	I			II			III		
	Pre	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*
1	88	98	+10	100	100	0	90	78	−12
2	100	95	− 5	109	100	− 9	106	83	−23
3	102	84	−18	90	100	+10	90	84	− 6
4	107	94	−13	94	82	−12	112	104	− 8
5	102	113	+11	113	95	−18	93	80	−13
6	115	102	−13	99	94	− 5	101	100	− 1
7	112	111	− 1	95	88	− 7	99	90	− 9
8	109	101	− 8	95	84	−11	104	96	− 8
9	93	94	+ 1	95	94	− 1	94	99	+ 5
10	112	91	−21	101	99	− 2	97	87	−10
11	95	97	+ 2	100	114	+14	90	87	− 3
12	112	97	−15	120	112	− 8	109	91	−18
13	102	90	−12	94	83	−11	92	91	− 1
14	105	97	− 8	100	109	+ 9	89	86	− 3
15	102	95	− 7	100	96	− 4	90	99	+ 9
16	105	95	−10	90	86	− 4	90	83	− 7
17	113	111	− 2	112	112	0	99	97	− 2
18	108	102	− 6	112	101	−11	106	103	− 3
19	114	102	−12	107	104	− 3	106	102	− 4
Ave.	105.0	98.3	− 6.7	101.4	97.6	− 3.8	97.7	91.6	− 6.1
S.D.	6.6	8.1	8.3	7.9	10.0	7.9	7.9	7.8	6.8
C.V.	6.3	8.2		7.8	10.2		8.1	8.5	
Reliability of Change—	More than 99 chances in 100			90–95 chances in 100			More than 99 chances in 100		

TABLE 5

Pre-Work and Post-Work Determinations and Direction of Change of Chlorides* in mg. per 100 cc. Blood During Periods I, II and III

Subject	I			II			III		
	Pre	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*
1	612	594	−18	591	547	−44	604	575	−29
2	592	574	−18	612	547	−65	626	584	−42
3	607	612	+ 5	508	526	+18	605	569	−36
4	604	586	−18	627	579	−48	584	590	+ 6
5	586	584	− 2	476	524	+48	604	599	− 5
6	576	460	−116	610	590	−20	607	631	+24
7	500	503	+ 3	600	584	−16	607	603	− 4
8	500	471	−29	553	563	+10	634	599	−35
9	526	466	−60	608	590	−18	630	573	−57
10	587	568	−19	610	607	− 3	569	576	+ 7
11	529	560	+31	599	607	+ 8	575	615	+ 4
12	537	531	− 6	584	571	−13	622	615	− 7
13	538	534	− 4	615	590	−25	605	590	−15
14	531	474	−57	597	586	−11	596	586	−10
15	542	553	+11	610	579	−31	572	610	+38
16	570	582	+12	582	580	− 2	576	567	− 9
17	593	613	+20	598	597	− 1	630	583	−47
18	563	579	+16	597	597	0	559	550	− 9
19	610	607	− 3	585	583	− 2	569	594	+25
Ave.	563.3	550.0	−13.3	587.6	576.2	−11.3	598.6	589.9	− 8.7
S.D.	40.6	49.9	33.3	26.8	22.7	24.8	23.9	20.7	27.2
C.V.	7.2	9.1		4.6	3.9		4.0	3.5	
Reliability of Change—		80–90 chances in 100			90–95 chances in 100			80–90 chances in 100	

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*The chlorides in this table and in the following tables have been calculated as sodium chloride.

TABLE 6

Pre-Work and Post-Work Determinations and Direction of Change of Calcium in mg. per 100 cc. Blood During Periods I, II and III

Subject	*I*			*II*			*III*		
	Pre	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*
1	10.40	14.65	+4.25	11.81	11.32	− .49	12.24	12.24	0
2	9.95	8.05	−1.90	11.56	9.84	−1.72	11.42	11.42	0
3	12.15	7.90	−4.25	11.28	10.82	− .46	12.20	14.70	+2.50
4	11.80	10.86	− .94	14.01	10.85	−3.16	12.20	11.71	− .49
5	11.98	9.38	−2.60	11.75	13.56	+1.81	12.20	11.22	− .98
6	10.58	13.58	+3.00	9.31	12.50	+3.19	10.78	11.52	+ .74
7	8.86	12.05	+3.19	10.75	12.20	+1.45	12.44	12.69	+ .25
8	10.33	11.81	+1.48	11.03	13.20	+2.17	11.61	12.10	+ .49
9	10.82	13.77	+2.95	10.54	11.27	+ .73	10.29	10.78	+ .49
10	13.92	9.85	−4.07	10.78	11.27	+ .49	9.49	10.85	+1.36
11	12.37	12.70	+ .33	12.20	12.70	+ .50	12.54	12.20	− .34
12	12.30	12.30	0	12.20	12.42	+ .22	12.53	13.26	+ .73
13	10.90	14.96	+4.06	10.78	10.54	− .24	11.03	11.76	+ .73
14	11.75	12.70	+ .95	11.71	13.25	+1.54	11.47	13.18	+1.71
15	11.35	9.54	−1.81	11.12	11.61	+ .49	11.52	11.27	− .25
16	11.90	13.86	+1.96	12.49	13.22	+ .73	12.25	10.62	−1.63
17	12.44	7.79	−4.65	12.25	11.27	− .98	10.62	11.30	+ .68
18	9.50	8.52	− .98	11.76	12.01	+ .25	11.75	11.07	− .68
19	11.03	11.27	+ .24	11.22	12.20	+ .98	10.78	12.25	+1.47
Ave.	11.295	11.359	+ .064	11.503	11.898	+ .395	11.545	11.902	+ .357
S.D.	1.217	2.171	2.726	.975	1.016	1.395	.768	.992	.970
C.V.	10.8	19.1		8.5	8.5		6.7	8.3	
Reliability of Change—	No reliable difference			70–80 chances in 100			80–90 chances in 100		

TABLE 7

PRE-WORK AND POST-WORK DETERMINATIONS AND DIRECTION OF CHANGE OF CREATININE IN MG. PER 100 CC. BLOOD DURING PERIODS I, II AND III

Subject	I			II			III		
	Pre	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*
1	1.40	1.99	+ .59	1.67	1.63	− .04	1.34	1.72	+ .38
2	1.36	2.27	+ .91	1.72	1.83	+ .11	1.34	2.93	+1.59
3	1.40	2.00	+ .60	1.65	1.67	+ .02	2.00	2.36	+ .36
4	1.69	3.00	+1.31	1.80	1.92	+ .12	2.03	2.09	+ .06
5	1.89	2.12	+ .23	1.89	2.01	+ .12	1.68	1.71	+ .03
6	1.89	1.76	− .13	1.53	1.72	+ .19	1.45	1.53	+ .08
7	1.94	2.25	+ .31	1.11	2.00	+ .89	1.38	1.81	+ .43
8	2.10	1.61	− .49	1.12	2.93	+1.81	1.73	2.00	+ .27
9	1.67	1.56	− .11	1.53	1.66	+ .13	1.45	1.53	+ .08
10	1.97	1.72	− .25	1.61	1.80	+ .19	1.53	1.44	− .09
11	1.87	1.99	+ .12	1.67	1.86	+ .19	1.51	1.66	+ .15
12	1.77	1.81	+ .04	1.84	2.05	+ .21	1.50	1.59	+ .09
13	1.87	1.94	+ .07	1.45	1.81	+ .36	1.42	1.42	0
14	2.11	1.64	− .47	1.77	2.14	+ .37	1.54	1.65	+ .11
15	2.05	2.16	+ .11	1.83	1.94	+ .11	1.35	1.36	+ .01
16	1.44	1.98	+ .54	1.61	1.77	+ .16	1.39	1.50	+ .11
17	1.81	2.31	+ .50	1.66	1.77	+ .11	1.26	1.33	+ .07
18	1.76	2.31	+ .55	1.66	1.83	+ .17	1.50	1.86	+ .36
19	1.59	1.81	+ .22	1.45	1.53	+ .08	1.37	1.41	+ .04
Ave.	1.767	2.012	+ .245	1.609	1.887	+ .278	1.514	1.731	+ .217
S.D.	.211	.329	.444	.200	.287	.408	.234	.387	.354
C.V.	11.9	16.4		12.4	15.2		15.5	22.4	
Reliability of Change—		95–98 chances in 100			More than 99 chances in 100			98–99 chances in 100	

In view of the fact that the work involved in the preceding Periods I, II and III had failed to have any significant effect on the calcium and chloride contents of the blood, it was believed that they would present no valuable information in constructing the metabolic picture of work. Consequently, these two determinations were dropped from all future analytical procedure, which consisted thereafter of the determinations of inorganic phosphorus, cholesterol, sugar and creatinine.

Table 8 gives the data for the control group doing physical work. It is evident that during physical work the inorganic phosphorus increase, the cholesterol increase, the sugar decrease and the creatinine increase are significant.

It appears that during physical work phospho-creatine is hydrolyzed with the production of inorganic phosphate and creatine. Sugar, a source of immediately available energy, is consumed in the process of work. Cholesterol, which increased during mental work with physical component, also increases during physical work.

3. *''No Work''*

Table 9 gives the data for the control group doing ''no work.'' The significant decrease in creatinine represents the decreased metabolism that accompanies a period of ''no work.'' The slight inorganic phosphorus increase may be attributed either to diurnal variation (19) or to the close approximation to the condition of sleep (8). The change is not reliable and hardly calls for explanation.

The correlations in 14 subjects between the pre-''no work'' bloods and the post-''no work'' bloods are, for cholesterol $+.93 \pm .03$, for sugar $+.79 \pm .04$, for creatinine $+.97 \pm .01$ and for inorganic phosphate $+.16 \pm .18$. It is evident that the individual maintained a biochemical stability over the period of 3 hours under the controlled laboratory conditions in cholesterol, sugar and creatinine.

Table 10 shows the gradation of changes from ''no work'' to physical work. The work sessions have been placed in the order of increasing physical work. It is evident that with a minor exception in the case of cholesterol, the order of increasing physiological cost is preserved.

4. *Discussion of Work Results*

As stated above (see p. 18), a proportionately greater amount of time is spent in overt muscular work in cancellation while a proportionately greater amount of time is spent in ''mental manipulation'' in the CAVD test.

TABLE 8

PRE-WORK AND POST-WORK DETERMINATIONS AND DIRECTION OF CHANGE OF INORGANIC PHOSPHORUS, CHOLESTEROL, SUGAR AND CREATININE IN MG. PER 100 CC. BLOOD DURING A 3-HOUR PERIOD OF PHYSICAL WORK IN 14 SUBJECTS

Subject	*Inorganic Phosphorus*			*Cholesterol*			*Sugar*			*Creatinine*		
	Pre	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*
1	3.55	3.61	+ .06	157	156	− 1	85	73	−12	1.72	2.83	+1.11
2	4.72	4.93	+ .21	131	177	+46	95	98	+ 3	1.38	1.55	+ .17
3	4.75	5.40	+ .65	163	201	+38	93	69	−24	1.30	2.41	+1.11
4	4.10	4.69	+ .59	137	150	+13	103	87	−16	1.44	1.48	+ .04
5	5.47	7.01	+1.54	155	171	+16	90	82	− 8	1.36	1.41	+ .05
6	3.75	4.84	+1.09	177	191	+14	97	80	−17	1.45	2.01	+ .56
7	3.89	4.08	+ .19	174	172	− 2	106	105	− 1	1.43	1.55	+ .12
8	5.00	4.72	− .28	164	183	+19	106	90	−16	1.42	1.79	+ .37
9	4.31	4.81	+ .50	180	173	− 7	90	90	0	1.77	2.01	+ .24
10	5.10	5.40	+ .30	205	214	+ 9	103	94	− 9	1.80	1.91	+ .11
11	5.24	6.15	+ .91	131	135	+ 4	103	94	− 9	1.83	2.05	+ .22
12	4.36	4.75	+ .39	168	169	+ 1	108	90	−18	1.48	1.56	+ .08
13	4.01	3.87	− .14	171	169	− 2	116	106	−10	1.53	1.69	+ .16
14	4.63	5.36	+ .73	256	254	− 2	97	95	− 2	1.50	1.56	+ .06
Ave.	4.491	4.973	+ .481	169.2	179.6	+10.4	99.4	89.5	− 9.9	1.529	1.844	+ .314
S.D.	.571	.851	.473	31.0	28.5	15.1	8.5	10.4	7.6	.172	.383	.352
C.V.	12.7	17.1		18.3	15.9		8.6	11.6		11.3	20.8	
Reliability of Change—		More than 99 chances in 100			95–98 chances in 100			More than 99 chances in 100			More than 99 chances in 100	

TABLE 9

PRE-WORK AND POST-WORK DETERMINATIONS AND DIRECTION OF CHANGE OF INORGANIC PHOSPHORUS, CHOLESTEROL, SUGAR AND CREATININE IN MG. PER 100 CC. BLOOD DURING A 3-HOUR PERIOD OF "NO WORK" (RELAXATION) IN 14 SUBJECTS

Subject	*Inorganic Phosphorus*			*Cholesterol*			*Sugar*			*Creatinine*		
	Pre	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*
1	4.49	3.61	− .88	143	140	− 3	95	95	0	1.64	1.71	+.07
2	5.17	5.14	− .03	176	177	+ 1	99	105	+6	1.62	1.67	+.05
3	4.60	5.21	+ .61	225	230	+ 5	98	99	+1	1.56	1.51	−.05
4	4.29	3.22	−1.07	163	159	− 4	103	101	−2	1.91	1.92	+.01
5	5.03	5.28	+ .25	180	183	+ 3	90	94	+4	1.71	1.71	0
6	4.55	6.20	+1.65	145	156	+11	99	94	−5	1.23	1.00	−.23
7	4.63	4.97	+ .34	174	182	+ 8	99	96	−3	1.65	1.63	−.02
8	4.36	5.81	+1.45	174	157	−17	90	95	+5	1.25	1.00	−.25
9	3.91	6.36	+2.45	188	181	− 7	99	99	0	1.30	1.28	−.02
10	4.97	4.29	− .68	203	205	+ 2	99	97	−2	1.57	1.45	−.12
11	4.72	4.57	− .15	143	150	+ 7	100	94	−6	1.55	1.46	−.09
12	4.29	3.37	− .92	167	145	−22	96	94	−2	1.50	1.50	0
13	4.17	2.83	−1.34	196	186	−10	116	112	−4	1.46	1.39	−.07
14	4.17	4.08	− .09	216	205	−11	99	103	+4	1.39	1.34	−.05
Ave.	4.525	4.639	+ .114	178.1	175.4	− 2.6	98.7	98.4	−0.3	1.524	1.469	−.055
S.D.	.348	1.076	1.077	24.6	25.3	9.4	6.2	5.6	3.7	.184	.253	.029
C.V.	7.7	23.2		13.8	14.4		6.2	5.7		12.1	17.2	
Reliability of Change—	No reliable change			70 chances in 100			No reliable change			95–98 chances in 100		

The average number of A's cancelled in 3 hours was 10,880 A's (see Table 15). In tapping, the metronome was set at 126 beats per minute. Every 5 minutes for one-half minute the subject tapped as fast as he could and these speed scores were recorded by electric counters. These speed scores, while not very accurate (because the counters occasionally jammed), average about 6600 taps. If there is added to this number the number of taps made in keeping time to the metronome, 20,412, that is, 126 beats × 162 minutes, the final average number of taps made during physical work (tapping) is about 27,012 taps, or more than two and one-half times the average number of A's cancelled in 3 hours. Thus, when we compare tapping and cancellation, it seems that in the case of tapping we have a right to speak of greater overt physical activity, and, conversely, in cancellation, when certain letters have to be picked out from other letters, the amount of mental activity may be said to be greater than in tapping.

Table 11 compares the changes occurring in "no work" and in physical work with those occurring in Periods I, II and III. There is no reliable difference between biochemical changes occurring during a 3-hour period of tapping and 3 hours of cancellation or 3 hours of taking an intelligence test.

There is a reliable difference between changes in creatinine, sugar and cholesterol occurring during a 3-hour period of "no work" and 3 hours of cancellation or 3 hours of taking an intelligence test. The decrease in creatinine in "no work" differs reliably from the increases in creatinine accompanying the work in Periods I and III. Sugar and cholesterol do not appear to change during "no work." Sugar decreases and cholesterol increases with work.

TABLE 10

GRADATION OF CHANGES IN MG. PER 100 CC. BLOOD FROM "NO WORK" THROUGH PHYSICAL WORK (INCREASING AMOUNTS OF PHYSICAL WORK INVOLVED)

Sessions	*Inorganic Phosphorus*	*Cholesterol*	*Sugar*	*Creatinine*
"No Work"	+.114	− 2.6	−0.3	−.055
Period III	+.338	+15.1	−6.1	+.217
Period I	+.392	+15.6	−6.7	+.245
Physical Work	+.481	+10.4	−9.9	+.314

Since there were 9 subjects who had participated in Periods I, II and III, "no work" and physical work, it was decided to construct a table similar to Table 11 but comparing the changes in "no

TABLE 11

Comparison of Changes in mg. per 100 cc. Blood in "No Work" and in Physical Work with Those of Periods I, II and III

Sessions	*Inorganic Phosphorus*	*Cholesterol*	*Sugar*	*Creatinine*
Period I	+.392	+15.6	−6.7	+.245
"No Work"	+.114	− 2.6	−0.3	−.055
Difference	.278	18.2	6.4	.300
Reliability of Difference	No reliable difference	98–99 chances in 100	98–99 chances in 100	98–99 chances in 100
Period I	+.392	+15.6	−6.7	+.245
Physical Work	+.481	+10.4	−9.9	+.314
Difference	.089	5.2	3.2	.069
Reliability of Difference	No reliable difference	No reliable difference	70 chances in 100	No reliable difference
Period II	−.079	+18.6	−3.8	+.278
"No Work"	+.114	− 2.6	−0.3	−.055
Difference	.193	21.2	3.5	.333
Reliability of Difference	No reliable difference	More than 99 chances in 100	80–90 chances in 100	More than 99 chances in 100
Period II	−.079	+18.6	−3.8	+.278
Physical Work	+.481	+10.4	−9.9	+.314
Difference	.560	8.2	6.1	.036
Reliability of Difference	98–99 chances in 100	70–80 chances in 100	90–95 chances in 100	No reliable difference
Period III	+.338	+15.1	−6.1	+.217
"No Work"	+.114	− 2.6	−0.3	−.055
Difference	.224	17.7	5.8	.272
Reliability of Difference	No reliable difference	More than 99 chances in 100	More than 99 chances in 100	More than 99 chances in 100
Period III	+.338	+15.1	−6.1	+.217
Physical Work	+.481	+10.4	−9.9	+.314
Difference	.143	4.7	3.8	.097
Reliability of Difference	No reliable difference	No reliable difference	No reliable difference	No reliable difference

work'' with physical work with those of Periods I, II and III in the same 9 subjects. This would be a check on the adequacy of the procedure of adding 5 ''new'' subjects to the group of 9 ''old'' subjects to serve as a control group. As stated above, the ''new'' subjects were of the same age range, educational, social and economic status as the ''old'' ones. Table 12 gives the data for the 9 subjects. The results are substantially the same as the results of Table 11. The reliabilities of the differences are slightly lower than those in Table 11 because the number of subjects is 9 and not 14, as in Table 11. It is thus evident that the procedure of adding ''new'' subjects to get a larger control group and thus greater reliability of results was a valid one.

Table 13 compares "no work" with physical work changes. It is evident that in cholesterol, sugar and creatinine the physical work changes appear to be significantly greater than those of "no work." Physical work produces a reliably greater decrease in sugar, increase in cholesterol, and increase in creatinine than "no work."

A study of the changes in variability of the blood constituents as a result of work done does not reveal many clear-cut results. Only sugar seems to show the picture of increasing variability of the post-work as compared with the pre-work determinations with increasing amounts of overt physical work. Tapping increased the sugar and creatinine variabilities most.

TABLE 12

COMPARISON OF CHANGES IN "NO WORK" AND IN PHYSICAL WORK AS AGAINST THOSE OF PERIODS I, II AND III IN THE SAME 9 SUBJECTS (IN MG. PER 100 CC. BLOOD)

Sessions	*Inorganic Phosphorus*	*Cholesterol*	*Sugar*	*Creatinine*
Period I	+.541	+15.2	− 6.8	+.344
"No Work"	+.530	− 0.3	+ 0.7	−.049
Difference	.011	15.5	7.5	.393
Reliability of Difference	No reliable difference	90–95 chances in 100	90–95 chances in 100	90–95 chances in 100
Period I	+.541	+15.2	− 6.8	+.344
Physical Work	+.506	+15.1	−10.1	+.499
Difference	.035	0.1	3.3	.075
Reliability of Difference	No reliable difference	No reliable difference	No reliable difference	No reliable difference
Period II	−.236	+22.1	− 2.1	+.244
"No Work"	+.530	− 0.3	+ 0.7	−.049
Difference	.766	22.4	2.8	.293
Reliability of Difference	80–90 chances in 100	More than 99 chances in 100	No reliable difference	98–99 chances in 100
Period II	−.236	+22.1	− 2.1	+.244
Physical Work	+.506	+15.1	−10.1	+.419
Difference	.742	7.0	8.0	.175
Reliability of Difference	95–98 chances in 100	No reliable difference	80–90 chances in 100	No reliable difference
Period III	+.237	+15.8	−10.3	+.314
"No Work"	+.530	− 0.3	+ 0.7	−.049
Difference	.293	16.1	11.0	.363
Reliability of Difference	No reliable difference	95–98 chances in 100	More than 99 chances in 100	90–95 chances in 100
Period III	+.237	+15.8	−10.3	+.314
Physical Work	+.506	+15.1	−10.1	+.419
Difference	.269	0.7	0.2	.105
Reliability of Difference	No reliable difference	No reliable difference	No reliable difference	No reliable difference

TABLE 13

COMPARISON OF "NO WORK" WITH PHYSICAL WORK CHANGES IN MG. PER 100 CC. BLOOD IN 14 SUBJECTS

Sessions	*Inorganic Phosphorus*	*Cholesterol*	*Sugar*	*Creatinine*
"No Work"	+.114	− 2.6	− 0.3	−.055
Physical Work	+.481	+10.4	− 9.9	+.314
Difference	.367	13.0	9.6	.369
Reliability of Difference	70–80 chances in 100	98 chances in 100	More than 99 chances in 100	More than 99 chances in 100

Table 14 shows the changes in the coefficients of variation from pre-work determinations to post-work determinations in the various blood constituents during Period I, Period III, physical work and "no work."

Table 15 gives the weights of the subjects in Periods I and III, cancellation scores (in thousands of A's) of Period I, cancellation times (in minutes) of Period II, and test scores on the CAVD Intelligence Test, Levels M–Q.

In order to determine whether the biochemical changes occurring in work are inter-related significantly, the changes for each period were inter-correlated.

Table 16 shows the inter-correlations between the biochemical changes in Period I, cancellation scores of Period I, weight in Period I and CAVD Intelligence Test scores. The correlations are generally low. There is no relation between the biochemical changes and work output when time is kept constant.

Table 17 gives the inter-correlations between biochemical changes in Period II, cancellation times of Period II, and CAVD scores. It is probable that competition and rivalry entered in this period since there was no time limit but merely limited output. The number of subjects were session varied from 2 to 9. Since the output was limited to 80 pages, the length of time the subject served in this particular session depended on his ability to perform

TABLE 14

CHANGES IN COEFFICIENTS OF VARIATION FROM PRE-WORK TO POST-WORK

	Period I	*Period III*	*Physical Work*	*"No Work"*
Inorganic Phosphorus	+ .5	+2.3	+4.4	+15.5
Cholesterol	+2.7	−2.2	−2.5	+ .6
Sugar	+1.9	+ .4	+3.0	− .5
Creatinine	+4.5	+6.9	+9.5	+ 5.2

TABLE 15

WEIGHTS OF SUBJECTS IN PERIODS I AND III, CANCELLATION SCORES (IN THOUSANDS) OF PERIOD I, CANCELLATION TIMES (IN MINUTES) OF PERIOD II, AND TEST SCORES ON THE CAVD INTELLIGENCE TEST, LEVELS M TO Q

Subject	*Weight I (in lbs.)*	*Weight III (in lbs.)*	*Cancellation Scores*	*Cancellation Times*	*CAVD*
1..........	175.5	175.0	11.48	101.4	150
2..........	157.3	158.5	10.71	108.9	134
3..........	153.8	154.0	9.12	123.7	84
4..........	170.5	172.0	9.80	133.2	116
5..........	142.0	141.0	7.77	129.8	94
6..........	170.0	171.0	10.83	113.9	86
7..........	199.5	198.0	12.50	112.7	133
8..........	150.0	149.0	7.92	171.9	118
9..........	171.0	172.5	12.60	100.3	72
10..........	151.0	155.0	9.66	115.1	125
11..........	180.0	183.0	11.90	100.0	78
12..........	206.0	205.0	12.05	116.3	112
13..........	134.0	137.0	12.70	103.2	145
14..........	145.5	149.0	11.24	120.5	80
15..........	152.0	153.0	13.99	90.3	55
16..........	157.5	155.0	9.39	128.5	85
17..........	187.0	186.0	13.31	93.2	166
18..........	167.0	169.0	11.28	121.5	103
19..........	149.0	152.0	8.47	148.1	131
Ave.......	164.1	165.0	10.88	117.50	108.8
S.D.......	19.1	18.1	1.77	19.18	32.2

the 80 pages of cancellation. The incentive to finish quickly and thus leave early probably acted as a spur to increased effort. In Period I, where the subject had to remain 3 hours anyway, no matter how rapidly he worked, rivalry could hardly enter to any great extent. A further evidence of the increased rate of work and the consequently increased activity in Period II as compared with Period I is shown in Table 18, which gives the number of A's cancelled per minute by each subject in Period I (limited time) and in Period II (limited output). The increase, however, in the number of A's cancelled per minute in Period II over the number of A's cancelled per minute in Period I is not reliable.

In Table 17, significant correlations appear to be those between creatinine change and cancellation times (+.59), between inorganic phosphorus change and cancellation times (+.50) and between sugar change and cancellation time (—.35). This means that the individual who took longest to perform the limited output of work tended to have the greatest increases in inorganic phosphorus and creatinine and the greatest decrease of sugar. It appears that under

TABLE 16

INTER-CORRELATIONS BETWEEN BIOCHEMICAL CHANGES IN PERIOD I, CANCELLATION SCORES OF PERIOD I, WEIGHT IN PERIOD I AND CAVD INTELLIGENCE TEST SCORES

(Note: Positive correlation between a series of increases and a series of decreases means large increases in one go with small decreases in the other; negative correlation between a series of increases and a series of decreases means large increases in one go with large decreases in the other.)

	Inorganic Phosphorus Change I	*Cholesterol Change I*	*Sugar Change I*	*Chlorides Change I*	*Calcium Change I*	*Creatinine Change I*	*Cancellation Scores*
Cholesterol Change I	+.44±.13						
Sugar Change I	−.28±.14	−.08±.15					
Chlorides Change I	−.27±.14	−.54±.11	+.15±.15				
Calcium Change I	+.40±.13	+.64±.09	+.20±.15	−.39±.13			
Creatinine Change I	+.26±.14	−.11±.15	+.10±.15	+.39±.13	−.23±.15		
Cancellation Scores	+.25±.14	−.01±.15	+.17±.15	+.09±.15	+.19±.15	−.01±.15	
Weight I	+.23±.15	−.10±.15	+.17±.15	+.10±.15	+.10±.15	+.21±.15	
CAVD	+.34±.14	+.29±.14	+.06±.15	+.17±.15	+.10±.15	+.26±.14	+.01±.15

TABLE 17

Inter-correlations Between Biochemical Changes in Period II, and Cancellation Times of Period II and CAVD Scores

	Inorganic Phosphorus Change II	*Cholesterol Change II*	*Sugar Change II*	*Chlorides Change II*	*Calcium Change II*	*Creatinine Change II*	*CAVD*
Cholesterol Change II	+.43±.13						
Sugar Change II	−.19±.15	+.23±.15					
Chlorides Change II	+.07±.15	−.01±.15	+.08±.15				
Calcium Change II	+.43±.13	−.03±.15	+.02±.15	+.52±.11			
Creatinine Change II	+.30±.14	+.10±.15	−.24±.15	+.17±.15	+.41±.13		
Cancellation Times	+.50±.12	+.01±.15	−.35±.14	+.36±.13	+.25±.14	+.59±.10	+.03±.15

conditions of limited output in cancellation the creatinine change and the inorganic phosphorus change tend to be correlated with the time engaged in work. It may be that those who worked slowly made harder work of it in a muscular way. It is evident that standardization of output does not standardize the physiological cost of work. However, from Table 16, it is evident that there is no relation between these biochemical changes and output when time is kept constant. This implies that time taken to perform work with output held constant is a better measuring rod of physiological cost, as determined by these biochemical methods, than amount of work performed with time held constant. Further corroboration of this point is received from the fact that the coefficients of variation of the inorganic phosphorus change and of the sugar change in Period II are greater than in Period I (see Tables 2 and 4). This means that with limited time there tends to be greater homogeneity in inorganic phosphorus change and in sugar change than with limited output. In the latter, the variability of change is greater in these two blood constituents.

TABLE 18

THE NUMBER OF A'S CANCELLED BY EACH SUBJECT PER MINUTE IN PERIOD I (LIMITED TIME) AND IN PERIOD II (LIMITED OUTPUT)

Subject	*Period I*	*Period II*
1	63.8	78.9
2	59.5	73.5
3	50.7	64.7
4	54.4	60.1
5	43.2	61.6
6	60.2	60.2
7	69.5	71.0
8	44.0	36.5
9	70.0	69.8
10	53.7	59.5
11	66.1	80.0
12	66.9	68.8
13	70.6	77.5
14	62.4	66.4
15	77.7	88.6
16	52.2	62.3
17	73.9	85.8
18	62.3	65.8
19	47.1	54.0
Ave.	60.4	67.6
S.D.	17.6	20.1
C.V.	29.1	29.7

Table 19 shows the inter-correlation between biochemical changes in Period III, weight in Period III, and CAVD intelligence scores.

TABLE 19

INTER-CORRELATIONS BETWEEN BIOCHEMICAL CHANGES IN PERIOD III, WEIGHT III, AND CAVD INTELLIGENCE TEST SCORES

	Inorganic Phosphorus Change III	*Cholesterol Change III*	*Sugar Change III*	*Chlorides Change III*	*Calcium Change III*	*Creatinine Change III*
Cholesterol Change III	−.15±.15					
Sugar Change III	+.09±.15	+.02±.15				
Chlorides Change III	−.12±.15	+.37±.13	+.27±.14			
Calcium Change III	−.04±.15	−.10±.15	+.09±.15	−.16±.15		
Creatinine Change III	+.19±.15	−.13±.15	−.62±.10	−.39±.13	−.08±.15	
Weight III	−.11±.15	+.20±.15	−.25±.14	−.01±.15	−.08±.15	+.07±.05
CAVD	−.45±.12	−.12±.15	−.47±.12	−.33±.14	+.11±.15	+.11±.15

The most significant correlations are those between sugar change and creatinine change (—.62), between sugar change and CAVD scores (—.47) and between inorganic phosphorus change and CAVD scores (—.45). This means that there was a tendency for those individuals who used up most of the immediately available energy to excrete into the blood the most products of muscular fatigue. It appears that the more intelligent individuals tended to use up the more sugar and excrete less inorganic phosphate than the less intelligent individuals. The author wishes to call attention to the correlation between inorganic phosphorus change in Period I and CAVD scores of +.34 as shown in Table 16. When the diffi-

TABLE 20

INTER-CORRELATIONS BETWEEN BIOCHEMICAL CHANGES IN PHYSICAL WORK

	Inorganic Phosphorus Change (P.W.)	*Cholesterol Change* (P.W.)	*Sugar Change* (P.W.)
Cholesterol Change (P.W.)	+.08±.18		
Sugar Change (P.W.)	−.06±.18	−.19±.17	
Creatinine Change (P.W.)	−.11±.18	+.26±.17	−.50±.14

TABLE 21

INTER-CORRELATIONS BETWEEN BIOCHEMICAL CHANGES IN PERIOD I AND THE BIOCHEMICAL CHANGES IN PERIODS II AND III, AND BETWEEN CANCELLATION TIMES (PERIOD II) AND CANCELLATION SCORES (PERIOD I)

	Inorganic Phosphorus Change I	*Cholesterol Change I*	*Sugar Change I*	*Chlorides Change I*	*Calcium Change I*	*Creatinine Change I*	*Cancellation Scores*
Inorganic Phosphorus Change II	−.20±.15						
Inorganic Phosphorus Change III	−.26±.14						
Cholesterol Change II		−.29±.14					
Cholesterol Change III		−.00±.15					
Sugar Change II			−.07±.15				
Sugar Change III			−.03±.15				
Chlorides Change II				+.24±.15			
Chlorides Change III				+.08±.15			
Calcium Change II					+.34±.14		
Calcium Change III					−.17±.15		
Creatinine Change II						−.45±.12	
Creatinine Change III						+.42±.13	
Cancellation Times							−.85±.04

culty of the mental work is increased the correlation becomes —.45. This would indicate that increasing the difficulty of the mental work produces a relatively smaller inorganic phosphate change in the more intelligent than in the less intelligent. This indicates that intelligence may be correlated with alterations in the inorganic phosphate content of the blood when the nature of the work performed is considered.

Table 20 shows the inter-correlation between biochemical changes in the physical work period. The most significant correlation is that between sugar change and creatinine change (—.50). This means that the individual who used up most sugar tended to excrete most creatinine into the blood stream.

Table 21 shows the inter-correlations between biochemical changes in Period I and the biochemical changes in Periods II and III, cancellation times (Period II) and the cancellation scores (Period I). The only significant correlation appears, obviously enough, to be that between cancellation scores and cancellation times (—.85), indicating, as one would expect, that the individual who cancelled most A's in Period I (limited time) tended to finish in the shortest time in Period II (limited output).

Table 22 shows the inter-correlations between biochemical changes in physical work and the biochemical changes in "no work." None of the correlations appear to be significant.

TABLE 22

Correlations Between Biochemical Changes in "No Work" and Physical Work

	Inorganic Phosphorus (N.W.)	*Cholesterol* (N.W.)	*Sugar* (N.W.)	*Creatinine* (N.W.)
Inorganic Phosphorus Change (P.W.)	+.20±.17			
Cholesterol Change (P.W.)		+.27±.17		
Sugar Change (P.W.)			+.26±.17	
Creatinine Change (P.W.)				−.02±.18

B. Ratings and Introspections

None of the subjects reported any difficulty in differentiating between mental and physical fatigue. Of course, it is possible that there may be a spurious distinction between local physical fatigue in fingers as physical and a more general diffuse fatigue as mental which may be physical also.

The results show that the subjects rated themselves as more physically fatigued after 3 hours of cancellation than after 3 hours of taking the CAVD test but more mentally fatigued after the CAVD test than after the 3 hours of cancellation. Of course it is possible that these ratings are determined by expectation and are not to be taken too seriously.

Table 23 gives ratings on physical fatigue and mental fatigue after Periods I, II and III. Low ratings correspond to little fatigue, high ratings to much fatigue.

Table 24 gives the ratings on physical fatigue and on mental fatigue after "no work" and after physical work. The results show, as one would expect, that the subjects rated themselves more physically fatigued after physical work than after "no work." They felt just as mentally fatigued after physical work as after "no work."

In general, fatigue ratings and biochemical changes do not show significant correlation. This may be due to the unreliability of fatigue ratings as measuring devices.

Table 25 shows the correlations of fatigue ratings with biochemical changes that occurred in Periods I, II, III and physical work.

A study of the introspective reports given by the subjects failed to reveal any significant connection between the introspections reported during experimental sessions and biochemical changes.

C. Summary of Results

1. There is no reliable difference between the changes occurring in cancellation and those in taking an intelligence test. Mental work with overt physical component consisting of 3 hours of cancellation produces certain biochemical changes. In general, there is an increase in inorganic phosphorus, an increase in cholesterol, a decrease in sugar and an increase in creatinine. Mental work with overt physical component consisting of a 3 hours' intelligence test of a difficult nature produces the same changes.

2. There is no reliable difference between changes occurring during a 3-hour period of tapping and 3 hours of cancellation or 3 hours of taking an intelligence test. However, there is a tendency for increases in biochemical changes to occur as the overt physical component of the task increases, but there is no such tendency as the "mentalness" of the task increases.

3. These three tasks (cancellation, intelligence test and tapping) differ reliably in biochemical changes from a 3-hour period of "no work" in cholesterol, sugar and creatinine.

TABLE 23

Ratings on Physical Fatigue and Mental Fatigue After Periods I, II and III (19 Subjects)

Subject	*Period I*		*Period II*		*Period III*	
	Physical Fatigue	*Mental Fatigue*	*Physical Fatigue*	*Mental Fatigue*	*Physical Fatigue*	*Mental Fatigue*
1	2	3	2	2	2	1
2	3	3	2	2	4	4
3	3	2	3	4	3	4
4	2	2	3	2	4	4
5	1	1	3	4	3	2
6	2	2	2	2	2	3
7	3	4	3	3	1	2
8	3	4	2	3	3	4
9	3	3	3	3	3	3
10	3	2	2	1	2	2
11	2	2	2	2	3	2
12	3	3	2	3	2	2
13	3	2	3	3	3	4
14	3	2	1	2	2	3
15	3	3	2	2	2	3
16	4	3	2	2	2	4
17	4	3	4	4	2	3
18	3	3	3	3	3	3
19	2	1	3	3	2	1
Ave.	2.7	2.5	2.5	2.6	2.5	2.8
S.D.	.8	.9	.6	.9	.8	1.1

TABLE 24

Ratings on Physical Fatigue and Mental Fatigue After "No Work" and Physical Work (14 Subjects)

Subject	*"No Work"*		*Physical Work*	
	Physical Fatigue	*Mental Fatigue*	*Physical Fatigue*	*Mental Fatigue*
1	2	1	2	1
2	1	2	2	2
3	2	2	2	2
4	2	2	2	2
5	1	1	3	2
6	2	2	3	3
7	2	2	2	2
8	2	3	2	2
9	3	3	3	2
10	1	1	4	1
11	1	1	3	2
12	2	2	2	1
13	3	2	2	1
14	3	1	3	2
Ave.	1.9	1.8	2.5	1.8
S.D.	.8	.6	.6	.5

TABLE 25

CORRELATIONS OF FATIGUE RATINGS WITH BIOCHEMICAL CHANGES IN PERIODS I, II AND III (19 SUBJECTS) AND IN PHYSICAL WORK (14 SUBJECTS)

	Inorganic Phosphorus	*Sugar*	*Creatinine*
Period I			
Mental Fatigue	+.39±.14	+.10±.15	+.01±.15
Physical Fatigue	+.45±.14	−.33±.15	−.01±.15
Period II			
Mental Fatigue	+.42±.14	−.18±.15	+.12±.15
Physical Fatigue	+.01±.15	−.31±.15	−.20±.15
Period III			
Mental Fatigue	+.08±.15	+.04±.15	+.24±.15
Physical Fatigue	+.16±.15	−.24±.15	+.37±.14
Physical Work			
Mental Fatigue	+.54±.13	+.06±.18	−.00±.18
Physical Fatigue	+.49±.14	+.22±.17	−.28±.17

4. As the work is made more observably muscular, there is an increase in the variability of sugar of the post-work as compared with the pre-work determinations. Tapping increases the sugar and creatinine variabilities most.

5. It appears that under conditions of limited output in cancellation the creatinine change and the inorganic phosphorus change tend to be correlated with the time engaged in work. It is evident that standardization of output does not standardize the physiological cost of work. There is no relation between these biochemical changes and output under conditions of limited time. Time taken to perform work under conditions of limited output appears to be a better index of physiological cost than output of work under conditions of limited time.

6. There is an indication that intelligence may be correlated with alterations in the inorganic phosphate content of the blood when the nature of the work performed is considered. The more intelligent have a smaller inorganic phosphate change than the less intelligent in performing difficult mental work, but a relatively greater inorganic phosphate change than the less intelligent in performing simple mental work, such as cancellation.

7. Fatigue ratings did not prove to have value as indices of biochemical changes occurring during work.

PART II

Mental Work with Minimal Physical Component

CHAPTER IV

METHODS AND PROCEDURE

A. Introduction

The results obtained in Part I indicate that there is no reliable difference between biochemical changes occurring in two types of mental performance, both having overt physical components. The degree of ''mentalness'' involved does not seem to have any effect on these changes. On the other hand, reference to Table 10 will reveal that gradation of these biochemical changes coincides with gradation of the amounts of physical work involved in the respective performances. There is still the problem of mental work with minimal physical component to be considered. It is probably impossible to entirely eliminate muscular work from any task. It is, however, possible to keep this physical component down to an irreducible minimum which is a necessary component of all mental work. Therefore it is the problem of this part of the experiment to determine whether mental work with the physical component largely eliminated differs metabolically, as determined by the biochemical methods used in this study, from ''no work'' of an equal length of time.

B. Methods

For the reasons stated above (see page 10), blood analyses were preferred to urine analyses; inasmuch as the calcium and chloride levels had not been significantly altered by work (as shown in Part I) it was decided not to include these determinations in the analytical procedure. The determinations of inorganic phosphorus, cholesterol, sugar and creatinine were employed in this part of the study. Discussions of these methods may be found in Chapter II.

C. Subject

The subject of this part of the experiment was the author. Inasmuch as the interpretation of the results of the whole experiment depended in large measure upon the results of this part of the experiment, and inasmuch as mental work in this part of the experiment was not measured by any written or spoken answers (see below), it is obvious that only an individual with the greatest degree of motivation could adequately serve as subject. The subject led a life of even tenor throughout the experimental period of ten weeks. The routine of one day was quite like that of the next day. Food habits were kept very constant.

D. Procedure

Since the problem of this part of the experiment was to determine whether or not mental work with minimal physical component entailed a physiological cost that could be measured by the biochemical methods of this investigation, it was decided to compare the effect of mental work with minimal physical component with the effects of ''no work.''

There were 20 sessions, each of one and one-half hours' duration. Ten sessions were ''no work'' sessions and ten sessions were mental work sessions. The subject attended two sessions per week, usually on Wednesdays and Fridays, for a period of ten weeks. To cancel the effects of any seasonal variation that might occur, a ''no work'' session was alternated with a mental work session.

The mental work consisted of multiplying 3-place numbers by 3-place numbers without recording or uttering the answer. These problems were devised by the author and were of unquestionable difficulty. The following are examples: 643×851; 954×623; 612×348. The author can attest to the degree of fatigue experienced after an hour and one-half of continuous mental multiplication of this nature. The subject was given practice sufficient to bring him up to his maximum ability in mental multiplication (as shown by a practice curve) prior to the experimental sessions. The mental work (as well as the ''no work'') was performed in a Morris chair in a semi-recumbent position. The problems, of which there were 40 to a page, were tacked on a specially constructed stand which rested on the arms of the chair so that the subject did not find it necessary to move any part of his body in performing the work. Shifting about in the Morris chair was kept to a minimum.

The subject reported at the laboratory without breakfast at 9 a.m. He rested for one-half hour in the Morris chair in a semi-recumbent position. A 10 cc. sample of blood was then taken by a technician. The subject multiplied 3-place numbers by 3-place numbers continuously for an hour and one-half without recording or uttering answers. At the end of the session another 10 cc. blood sample was taken by the technician. The same procedure was followed for the "no work" sessions except that there was no mental work of any kind. The subject spent the session either in sleep, idle revery or drowsy relaxation. Blood, of course, was taken before and immediately after the session.

The experimental sessions started the second week in July 1933 and ended the last week in September 1933, extending over a period of 10 weeks. The sessions were each of one and one-half hours' duration.

In total, 40 blood specimens of 10 cc. each, equal to 400 cc. of blood, were taken, and 160 blood determinations were performed by the author.

CHAPTER V

RESULTS

A. Work

1. *Mental Work with Minimal Physical Component*

After a period of mental work with minimal physical component, certain biochemical changes occur. In general, there is a decrease of inorganic phosphorus, a decrease of sugar and a decrease of creatinine.

Table 26 gives the pre-work and post-work determinations and direction of change of inorganic phosphorus, cholesterol, sugar and creatinine in mg. per 100 cc. of blood during 10 one and one-half hour periods of mental work in one subject. The averages, standard deviations and coefficients of variation are also given for the pre-work and post-work determinations. The reliabilities of the changes were computed according to Fisher's method (18, p. 104) used in dealing with small groups.

It would appear that the decrease in the sugar is due to fasting and not to work. This is confirmed by later comparisons with the results of the ''no work'' sessions. The decrease in inorganic phosphate and in creatinine is probably due to a reconversion of part of the inorganic phosphate and creatine from which creatinine is derived into phospho-creatine (25) (32) as a result of decreased metabolism. This occurs in states of rest in the organism.

2. *''No Work''*

After a period of ''no work'' certain biochemical changes occur. In general, there is a decrease of inorganic phosphorus, a decrease of sugar and a decrease of creatinine.

Table 27 shows the pre-work and post-work determinations and direction of change of inorganic phosphorus, cholesterol, sugar and creatinine in mg. per 100 cc. of blood during 10 one and one-half hour periods of ''no work'' (relaxation) in one subject. The averages, standard deviations and coefficients of variation are also given for the pre-work and post-work determinations in addition to the reliabilities of the biochemical changes.

In this case also, fasting would account for the decrease in sugar while decreased metabolism of the organism would account for the decreases of inorganic phosphate and creatinine with the probable

TABLE 26

Pre-Work and Post-Work Determinations and Direction of Change of Inorganic Phosphorus, Cholesterol, Sugar and Creatinine in mg. per 100 cc. Blood During Ten 1½ hr. Periods of Mental Work (Multiplication of 3-Place Numbers by 3-Place Numbers Without Recording or Uttering Answer) in One Subject

Session	Inorganic Phosphorus			Cholesterol			Sugar			Creatinine		
	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change
1	3.02	2.83	−.19	176	196	+20	127	121	−6	1.41	1.42	+.01
3	3.14	3.00	−.14	196	199	+ 3	94	93	−1	1.64	1.57	−.07
5	3.41	3.25	−.16	210	199	−11	94	89	−5	1.51	1.48	−.03
7	3.51	3.06	−.45	208	208	0	96	94	−2	1.34	1.27	−.07
9	3.33	2.86	−.47	191	182	− 9	99	94	−5	1.62	1.57	−.05
11	3.39	3.01	−.38	180	169	−11	97	94	−3	1.53	1.43	−.10
13	4.07	3.33	−.74	197	191	− 6	98	95	−3	1.63	1.45	−.18
15	2.74	2.71	−.03	176	174	− 2	96	94	−2	1.86	1.74	−.12
17	2.60	2.42	−.18	197	188	− 9	106	103	−3	1.83	1.72	−.11
19	3.25	3.31	+.06	199	196	− 3	102	94	−8	1.89	1.80	−.09
Ave.	3.246	2.978	−.268	193.0	190.2	− 2.8	100.9	97.1	−3.8	1.626	1.545	−.081
S.D.	.392	.271	.227	11.6	11.5	8.9	9.4	8.6	2.0	.178	.159	.050
C.V.	12.1	9.1		6.0	6.1		9.3	8.9		11.0	10.3	
Reliability of Change—		More than 99 chances in 100			Not reliable			More than 99 chances in 100			More than 99 chances in 100	

reconversion of part of the inorganic phosphate and creatine from which creatinine is derived into phospho-creatine (25) (32).

The correlations between the 10 pre-''no work'' bloods and the 10 post-''no work'' bloods in one subject are, for cholesterol +.79± .08, for sugar +.42± .18, for creatinine +.98± .01, and for inorganic phosphorus +.86± .05. It is evident that the individual maintained a biochemical stability over the period of one and one-half hours under the controlled laboratory conditions in the blood constituents studied.

3. *Discussion of Work Results*

There is no reliable difference between biochemical changes occurring during a one and one-half hour period of mental work with minimal physical component and a one and one-half hour period of ''no work.''

Table 28 compares mental work with ''no work'' changes. The differences between the changes are not reliable. Thus, when physical work has been to a large extent eliminated, it appears that mental work *per se* over a period of time does not produce any biochemical changes that a mere passage of the same period of time would not produce. This finding supplements the findings in Part I that the degree of ''physicalness'' of a task rather than its ''mentalness'' is responsible for physiological costs (see Table 10).

A study of the changes in variability of the blood constituents as a result of mental work and of ''no work'' does not reveal many significant results. It appears that ''no work'' makes the blood constituents more variable than does mental work. The author can offer no explanation for this. Table 29 shows the changes in coefficients of variation from pre-work determinations to post-work determinations in the various blood constituents during ''no work'' and during mental work.

Table 30 gives the inter-correlations between biochemical changes during 10 mental work periods. The tendency for creatinine decreases to go along with inorganic phosphate decreases is indicated by a not very high correlation of +.35. There is a tendency for small sugar decreases to go along with large creatinine decreases, both manifestations of a decreased metabolism. This is indicated by a correlation of —.40.

Table 31 gives the inter-correlations between biochemical changes during 10 ''no work'' periods. Again it is evident that large creatinine decreases go along with large inorganic phosphate

TABLE 27

Pre-Work and Post-Work Determinations and Direction of Change of Inorganic Phosphorus, Cholesterol, Sugar and Creatinine in mg. per 100 cc. Blood During Ten 1½ hr. Periods of "No Work" (Relaxation) in One Subject

Session	*Inorganic Phosphorus*			*Cholesterol*			*Sugar*			*Creatinine*		
	Pre	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*	*Pre*	*Post*	*Change*
2	3.32	3.49	+.17	194	197	+ 3	91	89	− 2	1.72	1.72	0
4	4.29	3.95	−.34	205	218	+13	100	88	−12	1.89	1.86	−.03
6	4.21	4.49	+.28	197	216	+19	97	101	+ 4	1.53	1.45	−.08
8	3.57	3.07	−.50	191	184	− 7	98	95	− 3	1.39	1.34	−.05
10	3.71	2.94	−.77	191	197	+ 6	94	90	− 4	1.63	1.50	−.13
12	3.21	2.92	−.29	167	150	−17	107	98	− 9	1.50	1.46	−.04
14	3.50	3.21	−.29	197	183	−14	96	95	− 1	1.82	1.67	−.15
16	3.13	2.81	−.32	192	177	−15	95	94	− 1	1.62	1.49	−.13
18	2.81	2.06	−.75	204	214	+10	96	94	− 2	2.23	2.10	−.13
20	3.00	2.94	−.06	223	208	−15	98	93	− 5	2.01	1.97	−.04
Ave.	3.475	3.188	−.287	196.1	194.4	− 1.7	97.2	93.7	− 3.5	1.734	1.656	−.078
S.D.	.464	.632	.329	13.4	20.3	12.8	4.0	3.8	4.2	.243	.239	.050
C.V.	13.4	19.8		6.8	10.4		4.1	4.1		14.0	14.4	
Reliability of Change—	95–98 chances in 100			No reliable change			95–98 chances in 100			More than 99 chances in 100		

TABLE 28

COMPARISON OF "NO WORK" CHANGES WITH MENTAL WORK CHANGES IN MG. PER 100 CC. BLOOD IN ONE SUBJECT

	Inorganic Phosphorus	*Cholesterol*	*Sugar*	*Creatinine*
"No Work"	−.287	−1.7	−3.5	−.078
Mental Work	−.268	−2.8	−3.8	−.081
Difference	.019	1.1	0.3	.003
Reliability of Difference	No reliable difference	No reliable difference	No reliable difference	No reliable difference

TABLE 29

CHANGES IN COEFFICIENTS OF VARIATION FROM PRE-WORK TO POST-WORK IN ONE SUBJECT

	Inorganic Phosphorus	*Cholesterol*	*Sugar*	*Creatinine*
"No Work"	+6.5	+3.6	−.1	+.4
Mental Work	−3.0	0	−.5	−.7

TABLE 30

INTER-CORRELATIONS BETWEEN BIOCHEMICAL CHANGES DURING TEN MENTAL WORK PERIODS IN ONE SUBJECT

	Inorganic Phosphorus Change (M.W.)	*Cholesterol Change* (M.W.)	*Sugar Change* (M.W.)	*Creatinine Change* (M.W.)
Cholesterol Change (M.W.)	+.22±.20			
Sugar Change (M.W.)	−.30±.19	−.13±.21		
Creatinine Change (M.W.)	+.35±.19	+.49±.16	−.40±.18	

TABLE 31

INTER-CORRELATIONS BETWEEN BIOCHEMICAL CHANGES DURING TEN "NO WORK" PERIODS IN ONE SUBJECT

	Inorganic Phosphorus Change (N.W.)	*Cholesterol Change* (N.W.)	*Sugar Change* (N.W.)	*Creatinine Change* (N.W.)
Cholesterol Change (N.W.)	+.06±.21			
Sugar Change (N.W.)	+.32±.19	+.17±.21		
Creatinine Change (N.W.)	+.52±.16	+.06±.21	−.44±.17	

decreases (+.52) and that large creatinine decreases go along with small sugar decreases (—.44) as one would expect in states of rest.

B. Summary of Results

1. There is no reliable difference between the changes occurring in mental work with minimal physical component and those occurring in "no work." Mental work with minimal physical component consisting of one and one-half hours of mental multiplication results in certain biochemical changes. In general, there is a decrease in inorganic phosphorus, a decrease of sugar and a decrease of creatinine in the blood. "No work," consisting of relaxation for a period of one and one-half hours, produces the same changes.
2. There is indication that in conditions of decreased metabolism, such as in mental work with minimal physical component and in "no work," the decreases of inorganic phosphate and the decreases of creatinine show fairly significant positive correlations. The decreases in inorganic phosphate and creatinine are probably due to the reconversion of part of the inorganic phosphate and creatine from which creatinine is derived into phospho-creatine. There is also indication, under these conditions, that large creatinine decreases go along with small sugar decreases.

CHAPTER VI

DISCUSSION OF RESULTS

A study of the results of Parts I and II reveals the fact that mental work *per se* exercises no positive influence on metabolic activity as determined by the methods employed in this investigation. This conclusion is arrived at by two different approaches to the problem of mental work. In Part I, by the method of concomitant variation (see Table 10), it was found that the significant biochemical changes that occurred varied with the degree of overt physical work and not with the degree of "mentalness" involved in the work. This would indicate that such biochemical changes as have been observed are principally due to the muscular work involved. Further conclusive support for this finding is derived from Part II where the results show that when the overt physical component of mental work is reduced to the minimum which is a necessary part of all mental work, there is no significant difference between the biochemical changes measured under these conditions and the biochemical changes measured in "no work." Other investigators, notably Benedict and Carpenter (3) and Benedict and Benedict (2) have found that mental work exercises no positive influence on the metabolic rate of the individual.

Of several investigations arriving at the opposite conclusion may be mentioned the study by Rounds, Schubert and Poffenberger (53), who found that mental multiplication resulted in a 28.8% increase in O_2 consumption over the resting rate in one subject. However, the subject recorded the answers to the problems. This required overt muscular work and may have accounted for the increases obtained in metabolic rate.

It is exceedingly difficult to separate mental work from muscular work. The organism reacts as a whole to any situation. Mental work and muscular work occur in varying proportions in all types of performances. In view of the fact that the physiological cost of mental work with minimal physical component is insignificant compared to the physiological cost of mental work with overt physical component, it is more than likely that uncontrollable factors, such as slight muscular movements, tensions, changes in heart rate and respiration, etc., may account for the increases in metabolic rate which were reported by several investigators (53) of the problem.

It may well be that the results reported by different investigators of the cost of mental work depend on these uncontrollable factors which may be more evident in some subjects than in others. In some subjects it is probable that increased metabolism will result. In other subjects, metabolism may not be affected. In that case, negative results would be more conclusive.

The results in this investigation show that when the overt muscular component of mental work approaches an irreducible minimum, mental work fails to register by the biochemical tests employed in this study. If there are any effects produced by mental work *per se* upon the total metabolic activity, it is evident that the current biochemical methods, particularly those employed in this study, do not appear to be sufficiently sensitive to detect these effects.

Since mental effort does not appear to produce any significant influence, as determined in the present study, upon the total metabolism of the organism, it is probable that the explanation of the fatigue after mental effort must be sought in the brain itself.

While the results of this investigation indicate that mental work *per se* does not appear measurably to affect the total body metabolism, there may still be a very intense biochemical activity present in particular areas of the brain as a result of mental work. The total mass of the active brain cells involved in mental work constitute a very small proportion of the total body involved, about 0.01% of the entire body (2, p. 82). This intense biochemical activity of the brain, if it is present as a result of mental work, may fail to be detected by the methods of testing the total metabolism.

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CHAPTER VII

CONCLUSIONS

From the results obtained in this study, the following conclusions may be drawn:

1. In tasks involving mental work with overt physical component,

   a. Increase of the physical component results in greater metabolic change as determined by the biochemical methods employed in this investigation,

   b. Increase of the mental component without increase of physical component does not result in greater metabolic change, as determined by the biochemical methods used in this study.

2. In tasks involving mental work with minimum physical component,

   Metabolic change, as determined by the biochemical methods of this investigation, does not differ significantly from that which occurs during "no work."

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